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A PORTABLE DIRECTION FINDER FOR 90 TO 7,700 KILOCYCLES

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ABSTRACT

This paper describes the development of a portable radio direction finder with but two controls (balancing and tuning) which operates over the frequency band from 90 to 7,700 kilocycles (3,300 to 39 meters). A shielding aluminum box contains all the receiving apparatus, including batteries, with the exception of the direction-finder coil which is supported on a bakelite shaft extending through the box and rotated by means of a handwheel under the box.

The direction finder is of the simple rotating-coil type. Automatic features are provided so that only a single tuning and a single balancing control are used. The receiving set is a superheterodyne which employs a standard Signal Corps amplifier and reduces the controls to a single one by mounting the main tuning condenser and the heterodyne generator tuning condenser on the same shaft. The latter condenser has connected in parallel with it an auxiliary condenser of slightly smaller capacity operated by means of a cam which may be slipped on the shaft carrying the two tuning condensers.

The wide frequency range is made possible by a set of seven interchangeable plug-in direction-finder coils, each with a corresponding heterodyne generator coil and a cam for operating the auxiliary tuning condenser. Another automatic condenser is connected in parallel with the main tuning condenser and is operated by a second cam on the shaft of the balancing condenser. Its function is to compensate for the detuning effect produced at the higher frequencies when the balancing condenser is operated. The center of each direction finder coil is grounded to the shield when in use. These coils vary in size from $12\frac{1}{4}$ inches square to $24\frac{1}{2}$ inches square, the former having only 2 turns and the latter 60 turns space wound in four layers. A small telescoping brass rod extending vertically through the center of each direction-finder coil, connected to the movable plates of the balancing condenser, serves as an auxiliary antenna for the purpose of sharpening the point of minimum signal. Means are provided so that bearings may be taken with respect to magnetic north.

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I. INTRODUCTION

The radio direction finder is an effective means of locating the source of a radio signal whether it comes from a ship in distress, from a radio beacon, from an airplane in flight, or any other source. Previously used radio¹ direction finders have been designed for use over a limited frequency range. With the rapid increase in the range of frequencies used for radio transmission purposes, the need has arisen for a direction finder which will function over a wide band of frequencies, and yet be portable and simple to operate. It is the purpose of this paper to describe the development of a portable direction finder of the simple rotating coil type operating over the frequency range of 90 to 7,700 kc (3,300 to 39 m). By the use of automatic devices the number of controls is reduced to two, one for tuning and one for balancing. It is so designed that it automatically compensates for the detuning effect produced by the operation of the balancing condenser. All apparatus, except the direction-finder coils, are shielded in an aluminum box. Means are provided for reading bearings relative to magnetic north.

II. DESCRIPTION OF APPARATUS

Early work on the development of this direction finder was done with the type of apparatus shown in Figure 1. It was thought before this work was started, that because of the peculiarities in the behavior of direction finding and receiving apparatus when used at the higher frequencies, the apparatus should not be too close to

¹ Direction and Position Finding by Wireless, by R. Keen; 1922. The Wireless Press (Inc.), 326 Broadway, New York, N. Y. Usages des Cadres et Radiogoniometrie, by R. Mesny; 1925. Etienne Chiron, 40, Rue de Seine, Paris, France. The Radio Direction Finder and Its Application to Navigation, by F. A. Kolster and F. W. Dunmore, B. S. Sci. Paper No. 428; 1922.

the operator. For this reason it was located in the brass box shown just under the direction-finder coil in Figure 1. This placed all apparatus above the operator's head. Four control extensions of insulating material dropped through the bottom of the box to the small shelf in front of the operator constituted the necessary adjust-



FIG. 1.—*Preliminary direction-finder model*

ing means for rotating the direction-finder coil, for balancing and tuning the direction-finder coil, and for tuning the heterodyne oscillator. The sound from the telephone receivers in the shielded box was carried through rubber tubing to a headset. Although this apparatus proved satisfactory and eliminated all body capacity

and effects due to the presence of the operator, it was found, after experimenting with it, that the extreme precautions taken to eliminate these effects were unnecessary. A new design, which is more portable



FIG. 2.—*Direction finder assembled and in use*

and easier to operate, was worked out as a result of the experiments with this first model and is described in this paper. It is shown set up in position for use in Figure 2 and dismantled in Figure 3.

1. RECEIVING SET

The receiving set used in this direction finder is a superheterodyne which employs a standard Signal Corps amplifier. The tuning controls have been reduced to a single one by mounting the main tuning condenser and the heterodyne generator tuning condenser on the same shaft. The shaft also carries a cam which operates an auxiliary variable condenser which maintains a constant frequency difference 66.7 kc (4,500 m) between the heterodyne frequency and the incoming frequency. The receiving set is shown in Figures 4 and 5. Figure 6 gives the circuit diagram, and Figure 7 gives it in simplified form.

In these diagrams *G* is the amplifier. Coils *I* and condensers *B*, *C*, *D* constitute the high-frequency heterodyne generator circuit. *H*, not shown in Figure 7, is the low-frequency heterodyne generator for CW reception. The direction-finder coil tuning condenser *A*

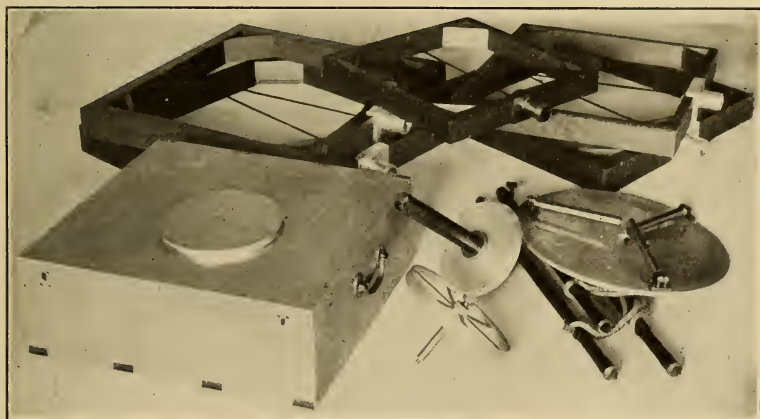


FIG. 3.—*Direction finder in the knockdown condition*

has a maximum capacity of $0.0005 \mu\text{f}$, and is mounted on the same shaft with the high-frequency heterodyne generator condenser *B*, which has a maximum capacity of $0.00025 \mu\text{f}$. A similar condenser, *C*, with a maximum capacity of approximately $0.0002 \mu\text{f}$ is connected in parallel with *B*. *C* is operated by means of a cam. This cam marked No. 1 in Figure 7 is so shaped that for a given direction-finder coil, *J*, and heterodyne-generator coil, *I*, the heterodyne frequency beating with the incoming frequency gives the predetermined intermediate frequency of 66.7 kc (4,500 m). The cam is made from a bakelite disk one-eighth inch thick which may be cut to the desired shape.

The cam-operated condenser carries a gear wheel (fig. 5) insulated from the shaft. A second gear wheel on a shaft terminating in a knob on the panel when meshed with the first gear provides a means

whereby condenser C may be hand operated. This provision for the hand operation of condenser C is necessary for the cam shape determination, but is not used thereafter unless it becomes necessary to make a new cam. The method of determining the cam shape is explained below.

The balancing condenser F , has connected in parallel with it a three-plate compensating condenser E , this latter condenser being

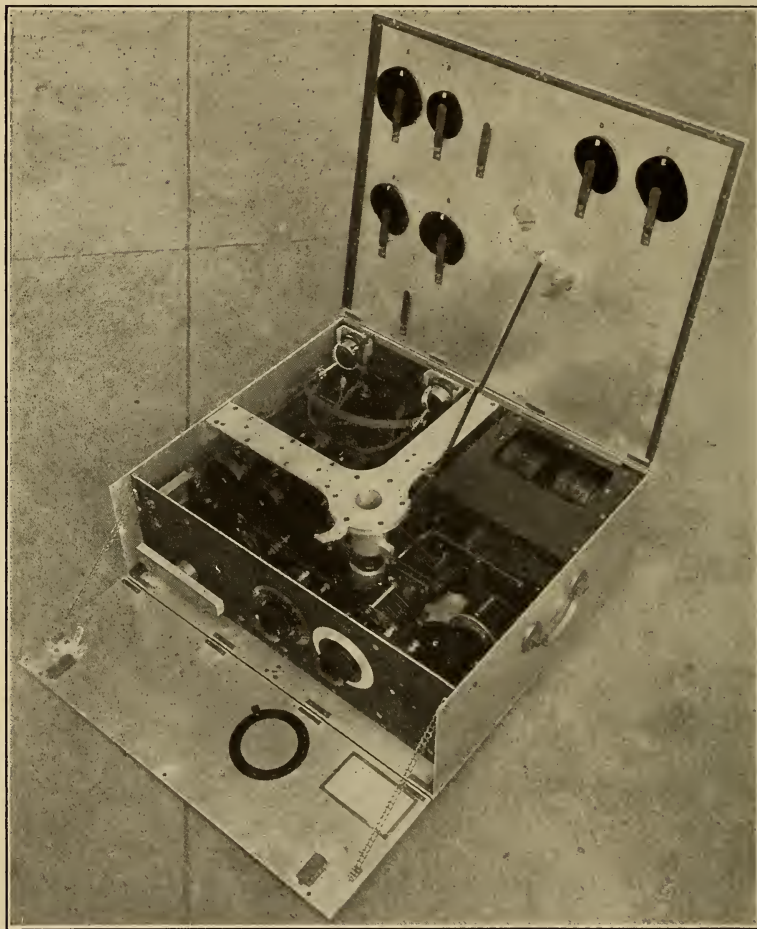


FIG. 4.—Direction finder unicontrol receiving apparatus

operated by cam No. 2 on the shaft of the balancing condenser. The purpose of E is to compensate for the detuning effect of balancing condenser F on condenser A .

D is a two-plate condenser used to check the cam shape determination. Switch S , not shown in Figure 7, controls the current supply

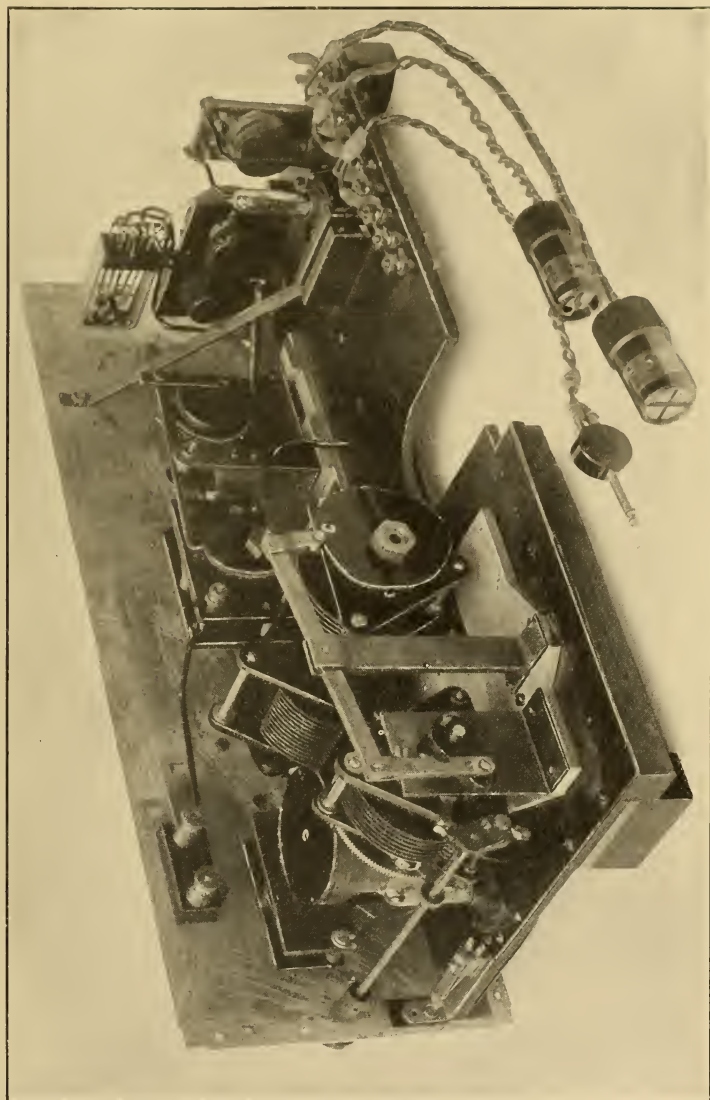


FIG. 5.—Rear view showing cam-operated condensers

to the tube filaments. It will be noted from the circuit diagram that the mid-point of the direction-finder coil is grounded as is also the filament circuit. The direction-finder coil tuning condenser *A* is connected across the terminals of the direction-finder coil. The input or grid of the first detector tube is connected to one side of this condenser. The other side of the condenser is connected to one of the

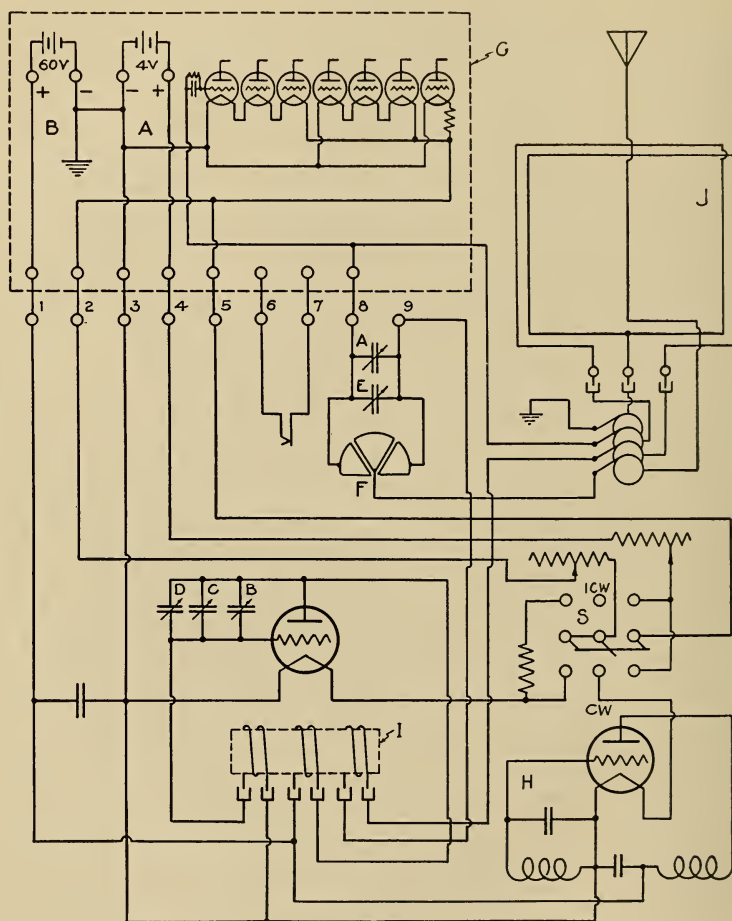


FIG. 6.—Direction-finder wiring diagram

fixed set of plates of the balancing condenser *F*, and to one of the plates of the automatic retuning condenser *E*. This connection gives greater stability to the circuits, requires a balancing condenser of less capacity because of the greater symmetry of this circuit, and increases somewhat the frequency range of a given direction-finder coil and tuning condenser at the higher frequencies on account of the

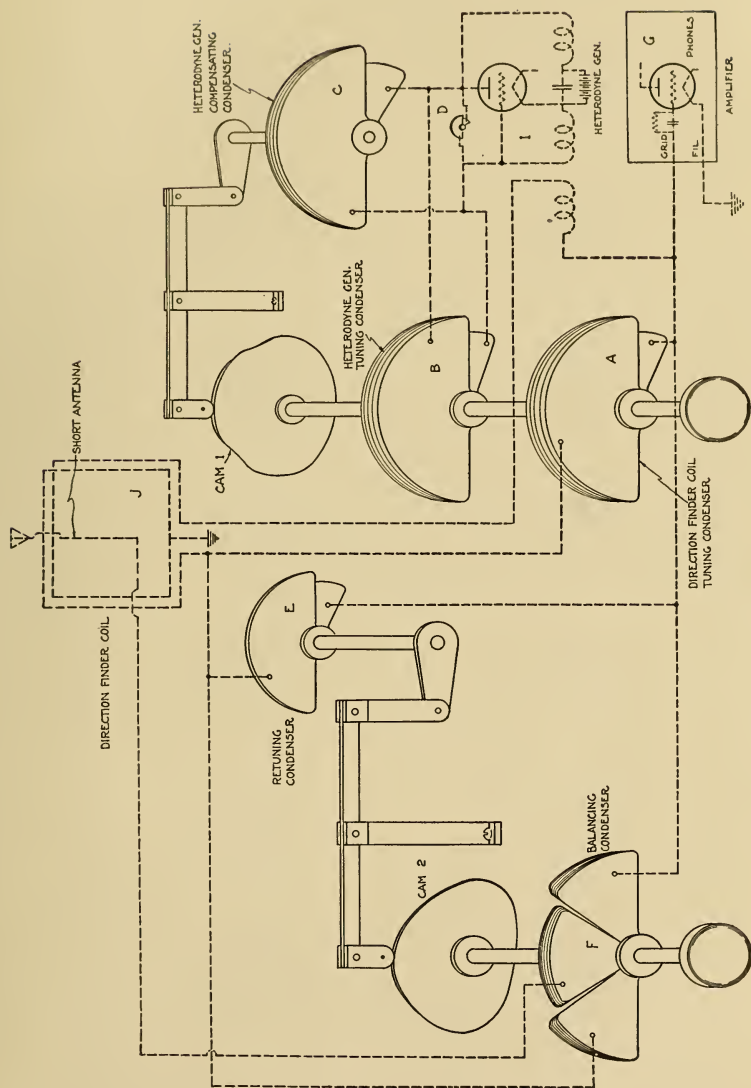


FIG. 7.—Direction-finder circuit showing connection of cam-operated condensers

removal of the tube capacity from across the terminals of the direction-finder coil.

The movable plates of the balancing condenser F are connected to an antenna, which is an integral part of each direction-finder coil and rotates with it. This antenna consists of a brass rod the height of the coil which passes through the center of the coil. Another rod is telescoped into this one, which, when extended, doubles the height of the antenna. Such an antenna on each coil was found to give sufficient antenna effect for good balancing. It was found that this small antenna connected to the movable plates of the balancing condenser was much more effective than grounding them.

(a) HETERODYNE GENERATOR COILS.—To cover the frequency range given above seven heterodyne generator coils are required. This necessitates seven cams, each of different shape; these with their respective heterodyne generator coils and corresponding direction-finder coil antenna cover the frequency range. Five of the seven direction-finder coil antennas are shown in Figure 3. The cams, heterodyne generator coils, and tuning dials are shown in Figure 8. These coils are of the plug-in type, having 6 terminal plugs, 4 of which constitute the terminals of the plate and grid coils, the other 2 being the terminals of the coupling coil which is in series with the direction-finder coil. The turns on this coupling coil vary for each of the coils. These coils are wound on tubes $2\frac{3}{4}$ inches outside diameter and $2\frac{1}{4}$ inches long. The coils are protected with a layer of varnished cambric and by two bakelite disks, one over each end of the coil. A socket is provided to receive these coils, to which the wires of the receiving set terminate. Heterodyne generator coil C is shown in position in this socket in Figure 4. The data for winding these heterodyne generator coils and their frequency ranges are given in Table 1. In each of these coils the plate winding is on the lower half of the coil form with the outside end of the coil connected to the plate. The grid winding is on the upper half of the coil form with the outer end connected to the grid. The grid and plate coils are wound with the same size wire and have the same spacing.

(b) THE INTERMEDIATE FREQUENCY AMPLIFIER.—The intermediate frequency amplifier (G , figs. 6 and 7) is one designed by the Signal Corps and is known as Type BC-116. It contains 7 Western Electric Type 215A tubes and is operated from a 4-volt storage or dry battery. It consists of a first detector, 3 stages of 66.7 kc (4,500 m) intermediate frequency amplification, second detector, and 2 stages of audio-frequency amplification. This amplifier is contained in the wooden box in the rear left corner of the aluminum box. (See fig. 4.)

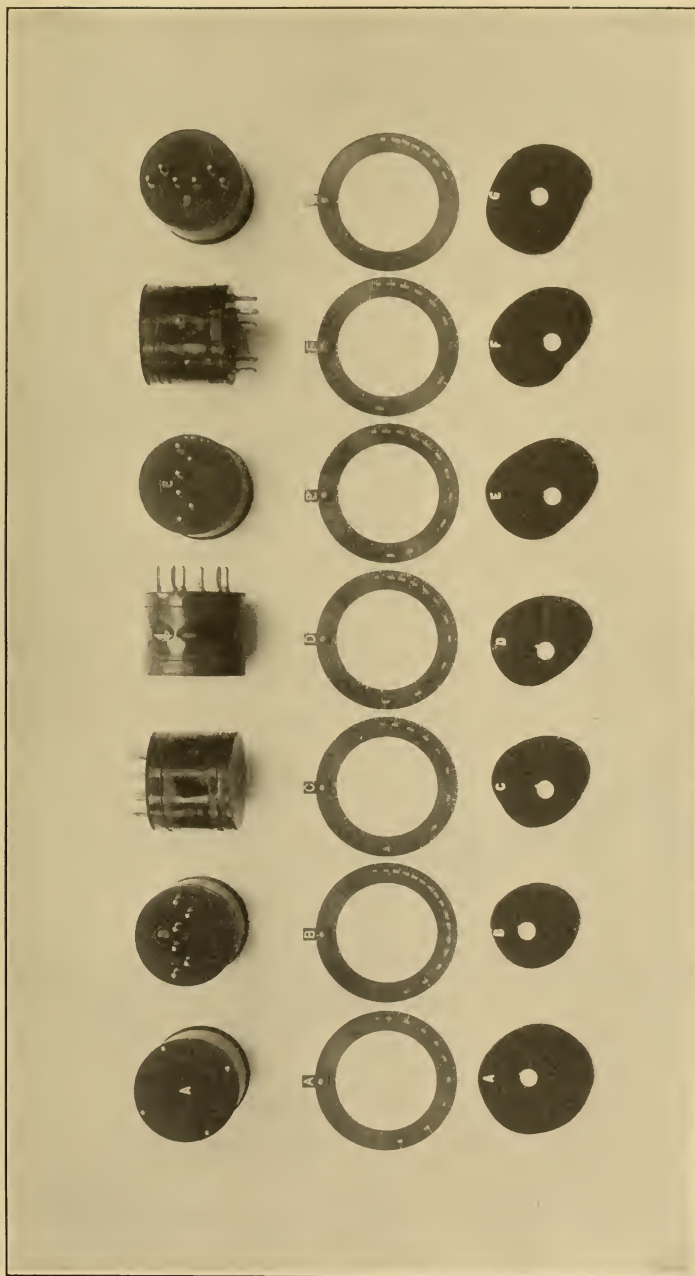


FIG. 8.—Sets of cams, heterodyne-generator coils, and disks calibrated in kilocycles

TABLE 1.—*Heterodyne generator coils*

Coil	Plate coil				Grid coil		Coupling coil				
	Frequency range	Turns	Size of wire	Spacing of turns	Distance from lower edge of coil to lower edge of coil form	Turns	Distance between inner end of grid and plate coils	Turns	Size of wire	Spacing between turns	Where wound
A-----	90-170 kc (3,330-1,764 m).	115	No. 40 A. W. G. single-silk enamel.	Close wound-----	$\frac{1}{8}$ inch	100	$\frac{1}{8}$ inch	16	No. 28 A. W. G. single-silk enamel.	Close wound-----	On upper end of coil form $\frac{1}{16}$ inch from upper end of grid coil.
B-----	165-310 kc (1,817-967 m).	81	No. 32 A. W. G. single-silk enamel.	do-----	$\frac{1}{4}$	73	$\frac{1}{16}$	12	No. 21 A. W. G. single-silk enamel.	do-----	Do.
C-----	305-665 kc (983-450 m).	54	No. 28 A. W. G. double-cotton covered.	do-----	$\frac{1}{16}$	42	$\frac{1}{16}$	6	No. 22 A. W. G. single-silk enamel.	do-----	Do.
D-----	650-1,500 kc (461-200 m).	20	do-----	do-----	$\frac{1}{2}$	22	$\frac{1}{4}$	4	do-----	Equal to gross diameter of wire.	On upper end of coil form $\frac{1}{4}$ inch from upper end of grid coil.
E-----	1,375-3,000 kc (218-100 m).	10	do-----	Distance equal to gross diameter of wire.	$\frac{1}{2}$	11	$\frac{1}{16}$	1	No. 28 A. W. G. double-cotton covered.	do-----	On lower edge of coil form $\frac{1}{4}$ inch from lower edge of plate coil.
F-----	2,550-6,000 kc (117-30 m).	5	No. 22 A. W. G. double-cotton covered.	do-----	$\frac{3}{4}$	4	$\frac{1}{8}$	(1)	No. 22 A. W. G. single-silk enamel.	do-----	On lower edge of coil form $\frac{1}{2}$ inch from lower edge of plate coil.
G-----	5,000-7,700 kc (60-39 m).	3	do-----	do-----	$\frac{3}{4}$	4	$\frac{1}{16}$	(2)	No. 22 A. W. G. double-cotton covered.	do-----	On lower edge of coil form $\frac{1}{4}$ inch from lower edge of tubing.

¹ Fraction of turn $\frac{1}{4}$ inches length.² Fraction of turn $\frac{1}{2}$ inches length.

(c) **LOW-FREQUENCY GENERATOR.**—In order to make possible continuous wave reception, a second generator is provided which is designed to give an audible beat frequency with the intermediate frequency. This second heterodyne circuit with tube may be seen at the right in Figure 5 and at *H* in Figure 6. The filament current to this tube is controlled by means of a switch on the panel so that when the switch *S* is in the CW (continuous wave) position the filament current is on, and when the switch is in the ICW (interrupted continuous wave) position the filament current is off, and a suitable resistance automatically thrown into the circuit to compensate for the change in load. This switch is automatically thrown to the "OFF" position when the box containing the receiving set is closed.

The complete receiving set operates from a 4-volt storage battery or from three No. 6 dry cells. Three 22½-volt batteries are used for the plate battery.

(d) **BALANCING AND RETUNING CONDENSERS.**—In order to obtain a sharp minimum a balancing or compensating condenser is used. This condenser, shown at *F*, Figure 7, and in Figure 9, consists of three movable plates and two sets of four fixed plates. The two sets of fixed plates are connected through the slip rings and brushes to the two terminals of the direction-finder coil. The movable plates are connected to a small antenna. This antenna, which is a telescoping brass rod permanently supported in the center of each direction-finder coil, may be seen in Figure 2. It makes connection

(through a fourth brush and slip ring to the movable plates of the balancing condenser) when the direction-finder coil is plugged into position. This antenna, though small, is sufficient when extended to its full length to produce the required balancing effect at the point of minimum signal when taking a bearing. At the higher frequencies it was noted that the balancing condenser has a marked detuning effect. This would necessitate retuning the set each time the balancing condenser is operated. To overcome this a small variable three-plate condenser *E*, Figures 6 and 7, was connected across the

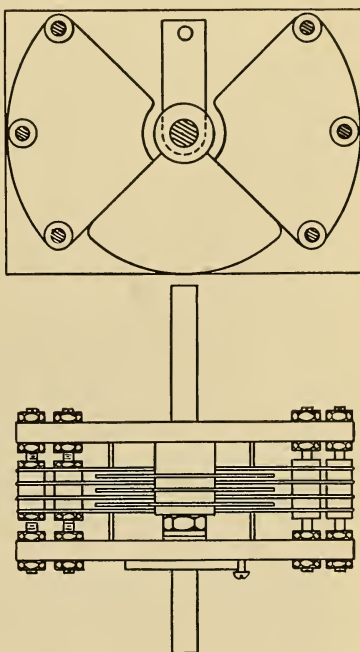


FIG. 9.—Balancing condenser

direction-finder coil tuning condenser. This small compensating condenser is operated by means of cam No. 2 (fig. 7) on the balancing condenser shaft, the cam being so shaped that the compensating condenser changes in capacity an amount equal and opposite to the change in capacity caused by the operation of the balancing condenser. This simplifies the operation of the direction finder at the higher frequencies.

2. DIRECTION-FINDER COILS

The direction-finder coils, seven in number, one for each of the heterodyne generator coils and corresponding cams and dial disks, vary in size from $12\frac{1}{4}$ inches square to $24\frac{1}{2}$ inches. These coils shown in Figure 10 are lettered from *A* to *G* with the frequency

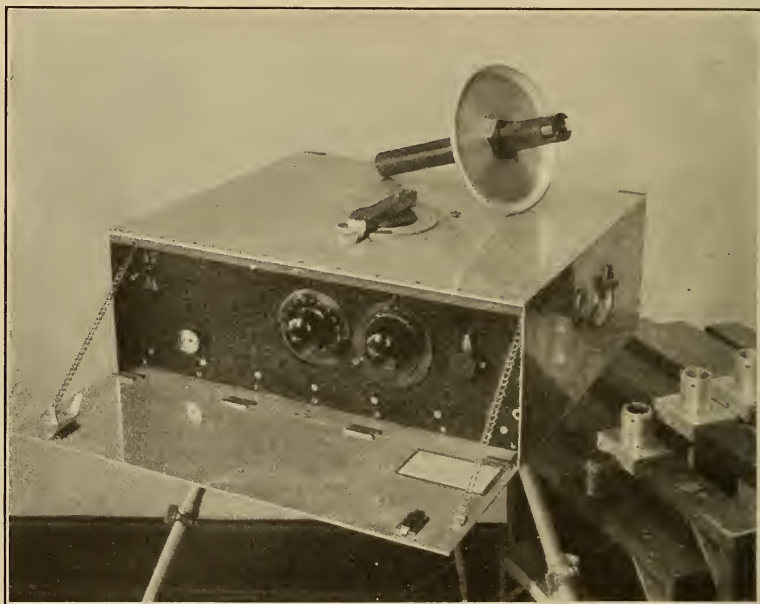


FIG. 10.—Magnetic compass in position for setting the index on true north

range marked on each. Each of these coils is provided with a socket containing four terminal plugs, two connected to the end of the coil, one to the center of the coil, and the fourth to the brass rod antenna. In this way the direction-finder coils may be quickly plugged on to the upper end of the shaft making electrical connection to the receiving set at the same time. The coils are inclosed, being wound on box frames made of wood. The winding data are given in Table 2.

TABLE 2.—*Direction-finder coils*

Coil	Frequency range	Turns	Length of layer on a side	Size of wire	Spacing of turns	Center tap
A...	{ 90-170 kc (3,330-1,764 m).	{ First layer, 18 turns..... Second layer, 18 turns..... Third layer, 18 turns..... Fourth layer, 6 turns.....	<i>Inches</i> 22 $\frac{7}{8}$ 23 $\frac{1}{4}$ 23 $\frac{3}{8}$ 24 (sq.)	{ No. 22 A. W. G. single-silk enamel.	<i>Inches</i> 1 $\frac{1}{8}$	{ Thirty-third turn from inside end.
B...	{ 165-310 kc (1,817-967 m).	{ First layer (inside), 10 turns. Second staggered with respect to first and bankwound with third, 10 turns. Third layer, 12 turns..... Fourth staggered with respect to third, 2 turns.	22 $\frac{3}{4}$ 23 $\frac{1}{4}$ 23 $\frac{3}{8}$ 24 $\frac{1}{4}$	{ No. 24 A. W. G. double cotton covered.	$\frac{3}{16}$ $\frac{3}{16}$ $\frac{7}{16}$ $\frac{7}{16}$	{ Fifth turn on third layer counting from inside end.
C...	{ 305-665 kc (983-450 m).	{ Inside layer, 8 turns..... Outside layer staggered with respect to inside layer, 10 turns.	23 $\frac{1}{4}$ 23 $\frac{3}{8}$	-----do----- -----do-----	$\frac{13}{16}$ $\frac{13}{16}$	{ At center of coil.
D...	{ 650 - 1,500 kc (460-200 m).	{ Eight turns.....	24 $\frac{1}{2}$	{ No. 22 A. W. G. double cotton covered.	$\frac{11}{16}$	Do.
E...	{ 1,375 - 3,000 kc (218-100 m).	{ Four turns.....	21	-----do-----	$\frac{13}{16}$	Do.
F...	{ 2,550 - 6,000 kc (117-50 m).	{ Two turns.....	18 $\frac{1}{2}$	{ No. 20 A. W. G. double cotton covered.	1 $\frac{1}{8}$	Do.
G...	{ 5,000 - 7,700 kc (60-39 m).	{ -----do-----	12 $\frac{1}{4}$	-----do-----	1 $\frac{1}{2}$	Do.

3. MISCELLANEOUS FIXTURES

(a) **SHAFT.**—The shaft is made of insulating tubing, in two sections, one of which is removable. The fixed section shown in Figure 4 contains the slip rings, plug terminals for making connection to the removable section, and a socket in its lower end for receiving the handwheel. The removable section shown in Figure 10 contains four socket connections in each end for connecting the slip rings to the terminals and center of the direction-finder coil and to the antenna on the direction-finder coil. The figure shows only three sockets; the fourth was added after the picture was taken. Details of these shaft sections are shown in Figure 11.

(b) **SCALE AND HANDWHEEL.**—The aluminum scale and handwheel are both detachable. The scale is engraved from 0 to 360°.

(c) **MAGNETIC COMPASS.**—The magnetic compass is arranged to plug into the opening which receives the movable shaft section before this section is put into position. It is shown in this position in Figure 10. The index mark on the large aluminum box is lined up with the compass needle and locked in position, after which the magnetic compass is removed. Radio bearings are then read on the scale with the index mark as a north reference.

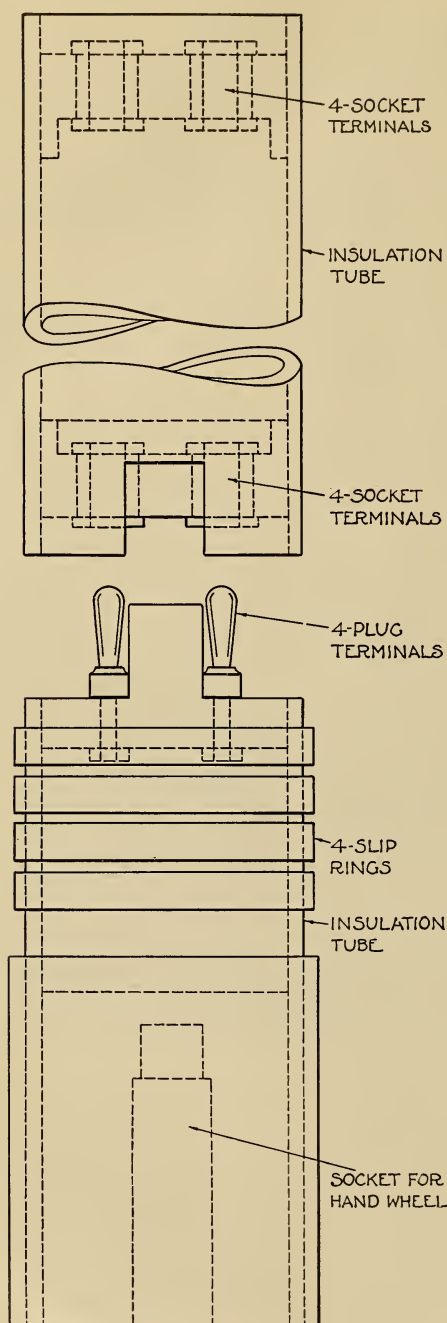


FIG. 11.—Direction-finder shaft showing jack and plug connections

(d) PANEL.—The aluminum panel shown in Figures 4 and 5 contains the filament-control switch, the balancing condenser dial, the main tuning or unicontrol dial, and two knobs. One knob operates condenser *D* (see fig. 7), and is for the purpose of determining whether the cams are shaped properly. The second knob is used only when shaping the cams. The unicontrol dial with one of the scales in position is shown in Figure 10. These scales shown in Figure 8 are provided with thumb tabs engraved with letters *A* to *G*, each scale being calibrated in kilocycles so that when used with its respective direction-finder coil and heterodyne coil and cam the receiving set may be adjusted to receive any desired frequency within its range.

The small hole in the left center of the panel is for the purpose of inserting a control knob for manually operating the three-plate retuning condenser which is ordinarily cam-operated by the balancing condenser. This control is used only during the process of determining the correct cam shape.

(e) ALUMINUM Box.—The aluminum box completely houses and shields the whole direction-finding apparatus except the direction-finding coils. This shielding is im-

portant, especially when receiving the higher frequencies, since the directive effects are blurred if any circuits except the direction-finder coil pick up power from the wave.

III. METHOD OF DETERMINING THE PROPER CAM SHAPE

1. CAMS ON UNICONTROL RECEIVING SET

Cam No. 1 for operating condenser *C* (fig. 7) is cut from a 4-inch bakelite disk, and is made as follows: A circular bakelite disk (fig. 12, No. 1) with keyway is slipped on a bushing on the rear end of the common shaft carrying the two condensers and locked in such a position that the disk is thrown in front of the rocker arm which carries the roller which is to ride on the periphery of the cam after it has been made. The roller shaft is pointed and just clears the disk. The control knob on the panel is pushed in meshing two sets of gears, thus making the heterodyne generator condenser *C* (fig. 7) hand operated. A signal is tuned in at every five division points on the scale of the main tuning dial with the two controls, the main tuning dial and the knob operating condenser *C*, as with an ordinary superheterodyne receiving set and the plunger on top of the aluminum box tapped at each tuning position. This plunger hits the rocker-arm roller, thus causing the pointed shaft through the roller on the rocker arm to dent the cam as shown in Figure 12, at 2. Circles the diameter of the roller are drawn about each dent as shown at 3 (fig. 12), and the cam cut out along the tangent line, the resulting cam being shown at 4 (fig. 12). To use the cam it is replaced with a washer in front of it which causes the rocker arm roller to ride on its periphery, thus operating condenser *C* in accordance with the cam shape.

2. CAM-OPERATED RETUNING CONDENSER

Cam No. 2, which operates the retuning condenser in conjunction with the balancing condenser, is made from a bakelite disk with a $1\frac{3}{8}$ -inch radius. The spring on the small three-plate condenser is removed and the small bakelite knob inserted through the hole in the panel to the right of the balancing condenser dial. The washer is taken off from the bushing on the shaft of the balancing condenser and the bakelite disk slipped on and fastened in position with a lock nut. The rocker arm is adjusted by means of a bakelite knob until the roller is in line with the periphery of the bakelite disk. The aluminum case is grounded. A signal is then tuned in with the balancing condenser at 50. The balancing condenser is then turned 10 divisions clockwise and the signal tuned in again by adjusting the three-plate compensating condenser. The top cover of the aluminum box is opened and the rocker arm tapped, thus making a dent on the disk. The cover is closed and the balancing condenser dial is then turned clockwise to the 20° position and the process repeated. This is continued every 10 divisions on either side of the 50° mark. The bakelite disk is then removed and cut to the shape as previously

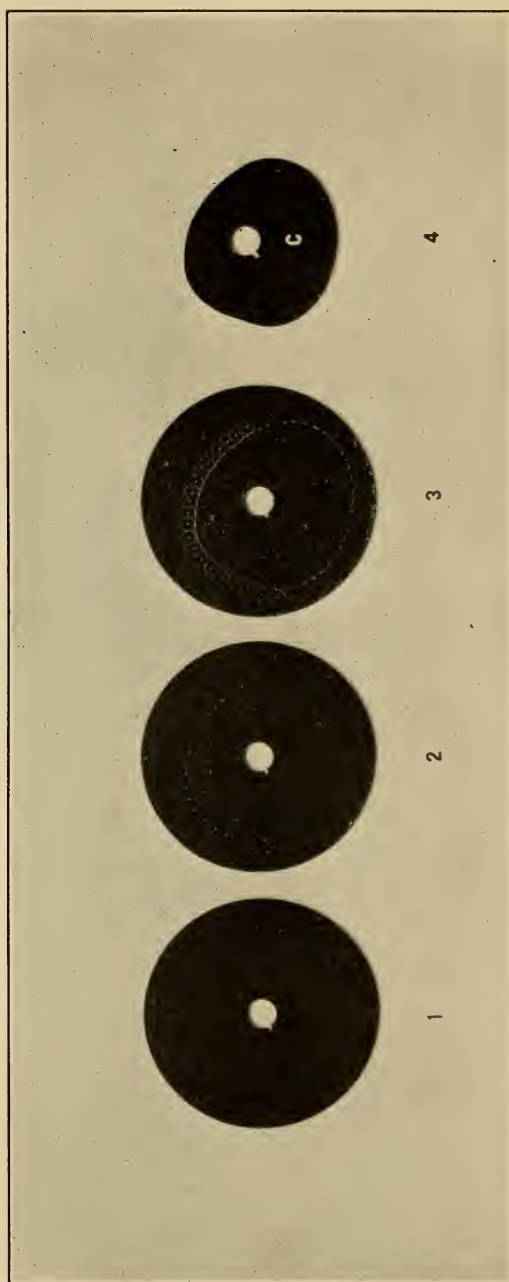


FIG. 12.—A cam in the four stages of construction

described. It is then replaced with a washer in front of it and the spring replaced so that the rocker arm rests on its periphery. The small tapping hammer provided in the cover for facilitating the other cam shape determinations was not provided in this case since there is but one cam to be formed.

IV. METHOD OF USING THE DIRECTION FINDER

In setting up the direction finder in the field the tripod is first placed in a convenient location as free as possible from surrounding objects, and the legs adjusted in length to make the table level. The protecting covers over the holes in the top and bottom of the aluminum box are removed and the box placed in position on the tripod. The box is oriented so that the panel faces approximately due north. The scale is placed in position on the shaft and the desired dial and superheterodyne generator coil plugged in position along with its respective cam. The top cover is closed and the magnetic compass placed in its socket over the hole into which the direction-finder shaft is later plugged. This compass is allowed to assume its north and south position and the case rotated until the index mark on the compass box is directly in line with the needle. The index mark on the large aluminum box is then rotated until it coincides with the index mark on the magnetic compass case. The lock nut is then tightened and the magnetic compass removed. The shaft is plugged into position and the proper direction-finder coil mounted on the end of it. The handwheel is next inserted underneath the aluminum box and screwed into position. The aluminum case is connected to ground and the head phones plugged in. The direction finder is then ready for use.

V. RESULTS OF TESTS

1. TESTS TO DETERMINE EFFECT OF CHANGING POSITION AND LENGTH OF ANTENNA

Tests were made in an open field 1 mile from a 500-watt transmitting station. It was found that the small antenna connected to the movable plates of the balancing condenser made possible a perfect null point on the minimum. With these plates grounded it was difficult to obtain a good minimum. The separate antenna first used was a 40-foot length of No. 18 wire stretched out on the ground. The change in settings of the balancing condenser necessary to maintain a perfect null point as the antenna was varied in length is given in Table 3.

TABLE 3
[1,100 kc]

Setting of balancing condenser	Length of antenna
	<i>Feet</i>
49.1	40
47.5	20
40.0	10

The balancing condenser scale is divided into 100 divisions. It was found that the 10-foot length if raised off the ground about 4 feet was about as effective as the 40-foot length on the ground. The effect of changing the position of the horizontal antenna 10 feet long and 4 feet high relative to the incoming wave front is given in Table 4.

TABLE 4

[580 kc]

Setting of balancing condenser	Position of antenna	Bearing
49.0.....	A	330.5
48.8.....	B	330.5
48.5.....	C	330.4
46.8.....	D	330.8
46.0.....	E	330.4
47.0.....	F	330.6
49.0.....	G	331.0
49.2.....	H	331.1

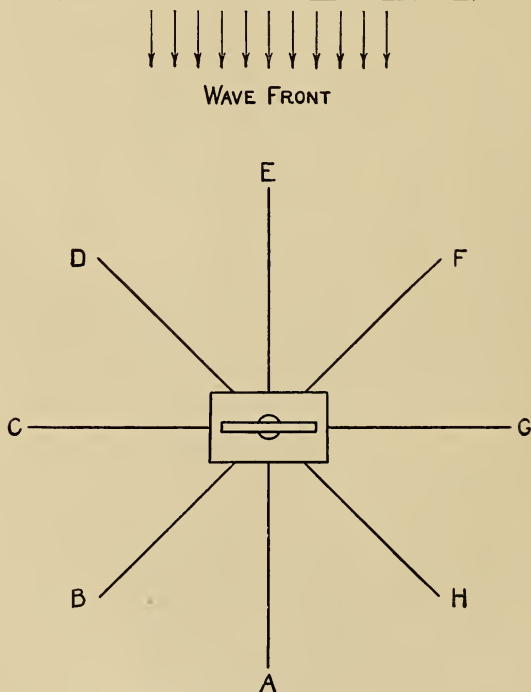


FIG. 13.—Antenna positions during test to determine change in bearing as antenna is shifted

Figure 13 gives the various positions of the antenna. This antenna was most effective with its free end pointing away from the transmitting station. A very short vertical antenna was found to be about as effective as the 10-foot horizontal antenna. This type was adopted and incorporated as part of each direction-finder coil. It is a telescoping brass rod extending through the center of each coil; when in use its length is twice the height of the coil; when not in use it is telescoped into the axis of the coil.

2. STUDY OF DIRECTIVE PROPERTIES OVER COMPLETE RANGE OF FREQUENCIES

In order to investigate the operation of the direction finder over its complete range of frequencies it was set up in an open field 2 miles from a 250-watt CW transmitting station. An antenna 4 feet long, connected to the movable plates of the balancing condenser, was used instead of the telescoping brass rod, as this test was made before the rod type of antenna had been installed. This antenna passed through an insulated bushing in the aluminum box^{*} and extended to the rear of the direction finder making an angle of 45° with respect to the ground. Two sets of bearings on different frequencies were taken on each direction-finder coil. The data obtained from this test is given in Table 5. In each case a reciprocal bearing was taken; that is, the coil was turned through 180° and a new null point obtained by readjusting the balancing condenser.

The true bearing from magnetic north to the transmitting station at the point where the direction finder was set up was 335°. It will be noted that between the frequencies of 125 and 3,000 kc (2,400–100 m) the maximum deviation from the true bearing was 2.7°, the average deviation being 1.2°. This shows that the calibration correction on these frequencies would not be great when the direction finder is operated in an open field. Between 4,900 and 6,000 kc (61–50 m), however, the maximum deviation was 10°, the average being 6.1°. The calibration correction at these frequencies is quite necessary. It is possible, however, that some influence external to the direction finder may have existed at these frequencies.

The maximum variation of the balancing condenser from its central or normal position was 12.2 divisions. As there are 50 divisions of variation on each side of the central position it is evident that the antenna was longer than necessary.

TABLE 5.—Radio bearings taken on different frequencies in an open field at a distance of 2 miles from a 250-watt CW transmitting station

[True bearing, 335°; reciprocal, 155°]

Frequency in kilocycles	Direction-finder coil	Bearing, in degrees	Setting of balancing condenser	Reciprocal bearing, in degrees	Setting of balancing condenser	Difference in bearings, in degrees	Average deviation from true bearing (degrees)
125 (2,400 m).....	A.....	{ 336.0	40.0	156.0	50.0	0	1.0
166.6 (1,800 m).....		{ 335.1	42.0	155.4	48.8	.3	.3
205 (1,463 m).....	B.....	{ 336.5	56.5	157.0	60.0	.5	1.7
300 (1,000 m).....		{ 334.8	62.2	155.2	57.2	.4	0
315 (952 m).....	C.....	{ 333.5	54.5	153.7	48.5	.2	1.4
600 (500 m).....		{ 337.5	51.1	158.0	51.0	.5	2.7
666 (450 m).....	D.....	{ 336.0	50.5	156.0	52.0	.0	1.0
1,300 (231 m).....		{ 335.4	50.4	156.0	51.5	.6	.7
1,500 (200 m).....	E.....	{ 337.1	50.0	157.7	49.1	.6	2.4
2,700 (111 m).....		{ 335.9	52.0	156.7	47.5	.8	1.3
3,000 (100 m).....	F.....	{ 333.5	49.5	154.7	52.0	1.2	.9
4,900 (61 m).....		{ 339.7	49.0	161.2	51.0	1.5	5.4
5,400 (55 m).....	G.....	{ 345.0	53.0	165.0	49.0	0	10.0
6,000 (50 m).....		{ 338.0	50.0	158.0	51.0	0	3.0
Average bearing.....		336.6					

3. EXPERIMENTS TO OBTAIN BEST TYPE OF ANTENNA

In order to investigate the effect of the antenna under conditions of use, the direction finder was placed under a tree with the rod type of antenna extending about $3\frac{1}{2}$ feet above the top of the direction-finder coil. This brought the top of the antenna within 4 feet of a limb of the tree directly overhead. A bearing was taken on a station operating on 100 kc (3,000 m). The balancing condenser setting, in order to obtain complete extinction of the signal, was 26; for the reciprocal bearing it was 90. This is 24 divisions from the normal position in one case and 40 divisions in the other, the normal position of the balancing condenser being 50. The direction finder was then moved out from under the tree, 25 feet away from it, and another set of the balancing condenser settings obtained on the same station. In this case the setting was 46, and for the reciprocal bearing it was 60. The antenna was considerably more effective since the settings from the normal position of the balancing condenser were 14 in one case and 10 in the other. This test shows that in cases where a direction finder is operated underneath a tree the antenna used should be slightly longer than twice the dimensions of the coil. This may be accomplished by plugging a brass rod 2 or 3 feet long on to the telescoping section when it is extended.

Tests were also made using an antenna extension over the coil consisting of a piece of bakelite tubing one-half inch in diameter and about $18\frac{3}{4}$ inches long, close wound with a single layer No. 38 A. W. G. gauge single silk enamel wire. This was found to be in resonance at about 2,000 kc (150 m). Other types and sizes of this form of antenna were tried, one consisting of a piece of tubing $1\frac{1}{8}$ inches in diameter and $33\frac{1}{2}$ inches long close wound full of No. 40 A. W. G. d. c. c. wire. This was found to be in resonance at 600 kc (500 m). In each case, for the frequency at which the antenna was in resonance, the antenna effect was very pronounced, and the necessary variations in the balancing condenser were consequently very small. As this type of antenna is only effective at the frequency for which it is tuned, it has little application except in cases where considerable work is to be done at one frequency and the direction finder is used under extreme conditions where it is very difficult to obtain the necessary antenna effect with the brass rod extension type of antenna.

The author is indebted to R. R. Gessford and Don F. Sutton for the construction of this direction finder and for helpful suggestions pertaining to many mechanical details, and to J. P. Buckley for much of the mechanical design work involved.

WASHINGTON, July 1, 1926.



1	Jan 1	Balance	100.00
2	Jan 2	Jan 1	100.00
3	Jan 3	Jan 2	100.00
4	Jan 4	Jan 3	100.00
5	Jan 5	Jan 4	100.00
6	Jan 6	Jan 5	100.00
7	Jan 7	Jan 6	100.00
8	Jan 8	Jan 7	100.00
9	Jan 9	Jan 8	100.00
10	Jan 10	Jan 9	100.00
11	Jan 11	Jan 10	100.00
12	Jan 12	Jan 11	100.00
13	Jan 13	Jan 12	100.00
14	Jan 14	Jan 13	100.00
15	Jan 15	Jan 14	100.00
16	Jan 16	Jan 15	100.00
17	Jan 17	Jan 16	100.00
18	Jan 18	Jan 17	100.00
19	Jan 19	Jan 18	100.00
20	Jan 20	Jan 19	100.00
21	Jan 21	Jan 20	100.00
22	Jan 22	Jan 21	100.00
23	Jan 23	Jan 22	100.00
24	Jan 24	Jan 23	100.00
25	Jan 25	Jan 24	100.00
26	Jan 26	Jan 25	100.00
27	Jan 27	Jan 26	100.00
28	Jan 28	Jan 27	100.00
29	Jan 29	Jan 28	100.00
30	Jan 30	Jan 29	100.00
31	Jan 31	Jan 30	100.00
32	Feb 1	Jan 31	100.00
33	Feb 2	Feb 1	100.00
34	Feb 3	Feb 2	100.00
35	Feb 4	Feb 3	100.00
36	Feb 5	Feb 4	100.00
37	Feb 6	Feb 5	100.00
38	Feb 7	Feb 6	100.00
39	Feb 8	Feb 7	100.00
40	Feb 9	Feb 8	100.00
41	Feb 10	Feb 9	100.00
42	Feb 11	Feb 10	100.00
43	Feb 12	Feb 11	100.00
44	Feb 13	Feb 12	100.00
45	Feb 14	Feb 13	100.00
46	Feb 15	Feb 14	100.00
47	Feb 16	Feb 15	100.00
48	Feb 17	Feb 16	100.00
49	Feb 18	Feb 17	100.00
50	Feb 19	Feb 18	100.00
51	Feb 20	Feb 19	100.00
52	Feb 21	Feb 20	100.00
53	Feb 22	Feb 21	100.00
54	Feb 23	Feb 22	100.00
55	Feb 24	Feb 23	100.00
56	Feb 25	Feb 24	100.00
57	Feb 26	Feb 25	100.00
58	Feb 27	Feb 26	100.00
59	Feb 28	Feb 27	100.00
60	Feb 29	Feb 28	100.00
61	Mar 1	Feb 29	100.00
62	Mar 2	Mar 1	100.00
63	Mar 3	Mar 2	100.00
64	Mar 4	Mar 3	100.00
65	Mar 5	Mar 4	100.00
66	Mar 6	Mar 5	100.00
67	Mar 7	Mar 6	100.00
68	Mar 8	Mar 7	100.00
69	Mar 9	Mar 8	100.00
70	Mar 10	Mar 9	100.00
71	Mar 11	Mar 10	100.00
72	Mar 12	Mar 11	100.00
73	Mar 13	Mar 12	100.00
74	Mar 14	Mar 13	100.00
75	Mar 15	Mar 14	100.00
76	Mar 16	Mar 15	100.00
77	Mar 17	Mar 16	100.00
78	Mar 18	Mar 17	100.00
79	Mar 19	Mar 18	100.00
80	Mar 20	Mar 19	100.00
81	Mar 21	Mar 20	100.00
82	Mar 22	Mar 21	100.00
83	Mar 23	Mar 22	100.00
84	Mar 24	Mar 23	100.00
85	Mar 25	Mar 24	100.00
86	Mar 26	Mar 25	100.00
87	Mar 27	Mar 26	100.00
88	Mar 28	Mar 27	100.00
89	Mar 29	Mar 28	100.00
90	Mar 30	Mar 29	100.00
91	Mar 31	Mar 30	100.00
92	Apr 1	Mar 31	100.00
93	Apr 2	Apr 1	100.00
94	Apr 3	Apr 2	100.00
95	Apr 4	Apr 3	100.00
96	Apr 5	Apr 4	100.00
97	Apr 6	Apr 5	100.00
98	Apr 7	Apr 6	100.00
99	Apr 8	Apr 7	100.00
100	Apr 9	Apr 8	100.00
101	Apr 10	Apr 9	100.00
102	Apr 11	Apr 10	100.00
103	Apr 12	Apr 11	100.00
104	Apr 13	Apr 12	100.00
105	Apr 14	Apr 13	100.00
106	Apr 15	Apr 14	100.00
107	Apr 16	Apr 15	100.00
108	Apr 17	Apr 16	100.00
109	Apr 18	Apr 17	100.00
110	Apr 19	Apr 18	100.00
111	Apr 20	Apr 19	100.00
112	Apr 21	Apr 20	100.00
113	Apr 22	Apr 21	100.00
114	Apr 23	Apr 22	100.00
115	Apr 24	Apr 23	100.00
116	Apr 25	Apr 24	100.00
117	Apr 26	Apr 25	100.00
118	Apr 27	Apr 26	100.00
119	Apr 28	Apr 27	100.00
120	Apr 29	Apr 28	100.00
121	Apr 30	Apr 29	100.00
122	May 1	Apr 30	100.00
123	May 2	May 1	100.00
124	May 3	May 2	100.00
125	May 4	May 3	100.00
126	May 5	May 4	100.00
127	May 6	May 5	100.00
128	May 7	May 6	100.00
129	May 8	May 7	100.00
130	May 9	May 8	100.00
131	May 10	May 9	100.00
132	May 11	May 10	100.00
133	May 12	May 11	100.00
134	May 13	May 12	100.00
135	May 14	May 13	100.00
136	May 15	May 14	100.00
137	May 16	May 15	100.00
138	May 17	May 16	100.00
139	May 18	May 17	100.00
140	May 19	May 18	100.00
141	May 20	May 19	100.00
142	May 21	May 20	100.00
143	May 22	May 21	100.00
144	May 23	May 22	100.00
145	May 24	May 23	100.00
146	May 25	May 24	100.00
147	May 26	May 25	100.00
148	May 27	May 26	100.00
149	May 28	May 27	100.00
150	May 29	May 28	100.00
151	May 30	May 29	100.00
152	May 31	May 30	100.00
153	Jun 1	May 31	100.00
154	Jun 2	Jun 1	100.00
155	Jun 3	Jun 2	100.00
156	Jun 4	Jun 3	100.00
157	Jun 5	Jun 4	100.00
158	Jun 6	Jun 5	100.00
159	Jun 7	Jun 6	100.00
160	Jun 8	Jun 7	100.00
161	Jun 9	Jun 8	100.00
162	Jun 10	Jun 9	100.00
163	Jun 11	Jun 10	100.00
164	Jun 12	Jun 11	100.00
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166	Jun 14	Jun 13	100.00
167	Jun 15	Jun 14	100.00
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183	Jul 1	Jun 30	100.00
184	Jul 2	Jul 1	100.00
185	Jul 3	Jul 2	100.00
186	Jul 4	Jul 3	100.00
187	Jul 5	Jul 4	100.00
188	Jul 6	Jul 5	100.00
189	Jul 7	Jul 6	100.00
190	Jul 8	Jul 7	100.00
191	Jul 9	Jul 8	100.00
192	Jul 10	Jul 9	100.00
193	Jul 11	Jul 10	100.00
194	Jul 12	Jul 11	100.00
195	Jul 13	Jul 12	100.00
196	Jul 14	Jul 13	100.00
197	Jul 15	Jul 14	100.00
198	Jul 16	Jul 15	100.00
199	Jul 17	Jul 16	100.00
200	Jul 18	Jul 17	100.00
201	Jul 19	Jul 18	100.00
202	Jul 20	Jul 19	100.00
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205	Jul 23	Jul 22	100.00
206	Jul 24	Jul 23	100.00
207	Jul 25	Jul 24	100.00
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209	Jul 27	Jul 26	100.00
210	Jul 28	Jul 27	100.00
211	Jul 29	Jul 28	100.00
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215	Aug 2	Aug 1	100.00
216	Aug 3	Aug 2	100.00
217	Aug 4	Aug 3	100.00
218	Aug 5	Aug 4	100.00
219	Aug 6	Aug 5	100.00
220	Aug 7	Aug 6	100.00
221	Aug 8	Aug 7	100.00
222	Aug 9	Aug 8	100.00
223	Aug 10	Aug 9	100.00
224	Aug 11	Aug 10	100.00
225	Aug 12	Aug 11	100.00
226	Aug 13	Aug 12	100.00
227	Aug 14	Aug 13	100.00
228	Aug 15	Aug 14	100.00
229	Aug 16	Aug 15	100.00
230	Aug 17	Aug 16	100.00
231	Aug 18	Aug 17	100.00
232	Aug 19	Aug 18	100.00
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236	Aug 23	Aug 22	100.00
237	Aug 24	Aug 23	100.00
238	Aug 25	Aug 24	100.00
239	Aug 26	Aug 25	100.00
240	Aug 27	Aug 26	100.00
241	Aug 28	Aug 27	100.00
242	Aug 29	Aug 28	100.00
243	Aug 30	Aug 29	100.00
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274	Sep 30	Sep 29	100.00
275	Oct 1	Sep 30	100.00
276	Oct 2	Oct 1	100.00
277	Oct 3	Oct 2	100.00
278	Oct 4	Oct 3	100.00
279	Oct 5	Oct 4	100.00
280	Oct 6	Oct 5	100.00
281	Oct 7	Oct 6	100.00
282	Oct 8	Oct 7	100.00
283	Oct 9	Oct 8	100.00
284	Oct 10	Oct 9	100.00
285	Oct 11	Oct 10	100.00
286	Oct 12	Oct 11	100.00
287	Oct 13	Oct 12	100.00
288	Oct 14	Oct 13	100.00
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304	Oct 30	Oct 29	100.00
305	Oct 31	Oct 30	100.00
306	Nov 1	Oct 31	100.00
307	Nov 2	Nov 1	100.00

